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A socio-technical perspective on low carbon investment challenges – Insights for UK energy policy

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ABSTRACT

The UK is moving into a new phase of energy governance which is characterised by significant demand for new investment to meet long term climate policy objectives and to address shorter term energy security challenges. This paper examines how contributions from the socio-technical systems approach can be operationalised to address the policy and societal challenge of large scale investments in low carbon energy infrastructure. Research on socio-technical transitions explores the dynamics of long term structural change in capital intensive systems such as energy, housing and water supply, seeking to redirect them towards more sustainable long term trajectories. Focusing on the UK electricity generation sector, the paper expands on three key low carbon investment challenges where socio-technical research can provide useful insights – (1) understanding long term uncertainty and investment risks; (2) avoiding technological lock-in; and (3) accelerating the diffusion of low carbon finance 'niches'.

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1. Introduction

In order for low carbon energy transitions to be realised large scale and long term capital investment will be required in a range of new infrastructure assets. Infrastructure, in a general sense, refers to the material basis of socio-technical systems – power stations, rail networks, ports, airports, pipes and wires etc. This has always been an important public policy issue because infrastructure supports the delivery of essential societal services, such as power for electrical devices and mobility. Governments have historically played a central role in infrastructure investment because of the wider social and economic benefits that it brings, but also because securing investment in these assets requires a long term and consistent governance framework. The balance between public and private investment has varied, though, between different types of infrastructure and according to the relative dominance of different political views of the role of markets in economic decision-making.

A strongly market-oriented framework for energy infrastructure investment has been followed in the UK since the early 1990s, with this model increasingly being followed in other countries. This reflects a view that markets for the delivery of societal services would bring about the incentives for private actors to invest in infrastructure assets, leading to greater economic efficiency and socially optimal outcomes. This model was strongly influenced by neo-classical economic thinking (Helm, 2003). However, this framework is increasingly challenged by the need for high levels of investment to meet other societal objectives of reducing carbon emissions and maintaining energy security, whilst maintaining affordability of energy services to consumers and businesses. In order to deal with these new complexities it is likely that a rebalancing of the relationship between governments and markets will be required (Pearson and Foxon, 2012). The energy policy framework which emerges will need to address a number of key questions: What kinds of policies can effectively mobilise finance and deliver low carbon forms of infrastructure investment? How is uncertainty and investment risk managed by public and private actors? And how are long and short term policy objectives reconciled?

The purpose of this paper is to explore the ways in which studies of socio-technical systems and their long term dynamics can provide useful insights which help to address these complex questions. The origins of the field can be traced back to the work of the historian of technology Thomas Hughes who charted the early emergence and expansion of 'large technical systems' (LTS) such as electricity supply (Hughes, 1983). Hughes and colleagues highlighted the role of pioneer 'system builders' such as Thomas Edison, and how, over time, these infrastructures develop a systemic character through a process of mutual shaping of the technical system and its wider social environment (Summerton, 1994; Coutard, 1999; Vleuten, 2004). More recent contributions have sought to account for the transformation of these now mature systems in the context of climate change, energy security and other drivers of change (Magnusson, 2012; Foxon, 2013).

Both the historically orientated LTS approach and the transitions perspective are grounded in the wider field of technology studies which seeks to account for the social character and implications of technical change (Williams and Edge, 1996; Bolton and Foxon, 2014; Mackenzie and Wacjman, 1999). Unlike neo-classical economics, which has formed the intellectual basis for energy policy in the UK since the 1980s, strands of technology studies such as this view technical change as a dynamic non-linear process, where outcomes are not determined by markets, but shaped by a wider set of social processes. A systems framing is adopted in which the market is embedded in socio-technical 'regimes' which are alignments of institutions, infrastructures and actors which provide stability to and underpin the delivery of essential societal services. Central to the analysis is how fundamental and long term changes to regimes occur, focusing on the de-stabling effects of radical innovations which emerge from typically dispersed 'niche' spaces, and changes in wider socio-technical 'landscapes', including macro level social, economic and technological trends (Rip and Kemp, 1998; Geels, 2002b). Our purpose is not to undertake a systematic review of the entire body of socio-technical systems literature (For overviews see: Markard et al., 2012; Smith et al., 2010; van den Bergh et al., 2011; Vleuten, 2004), rather we draw selectively from key concepts and contributions to the field to consider specific areas where we believe socio-technical thinking can help to contribute to the low carbon investment debate.

Although questions of finance and investment have not been an explicit focus of this field of research to date, though see (Geels, 2013), there has been some engagement with the issue, for example with a recent special issue of this journal focusing on the implications of the economic-financial crisis for the

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prospects of transitions to more environmentally sustainable systems (van den Bergh, 2013). While this has been highly relevant to the potential effects of changes at a macro or 'landscape' level (Antal and van den Bergh, 2013; Loorbach and Lijnis Huffenreuter, 2013), there is a need to understand in more depth how institutional realignments and policy changes influence infrastructure investments in specific contexts and in relation to individual socio-technical 'regimes' e.g. the electricity generation and supply regime. Through a number of illustrative examples the paper highlights how a more nuanced understanding of the complex interrelationships between long term technical change and social contexts, and the non-linear dynamics of innovation processes implicit in socio-technical studies can usefully inform policy debates in relation to low carbon investments.

The main empirical focus of the paper is on the UK electricity generation sector. The need to provide adequate and appropriate forms of public financial support to incentivise high levels of private investment in power generation is currently framing the design of one of the main UK low carbon policies – Electricity Market Reform. Section 2 outlines the specific policy issues being debated in the UK. In Section 3, we expand upon three areas in which socio-technical studies can contribute to an analysis of low carbon investment in this sector: (1) framing and understanding uncertainty and investment risks through the articulation of transition pathways, (2) emphasising long term time horizons and avoiding technological lock-in, and (3) accelerating the diffusion of low carbon finance 'niches'. In Section 4 we reflect on the contribution of socio-technical research to addressing the low carbon investment policy challenges and the limits of the approach. We highlight that the nature of the contribution is in providing systemic frameworks based on an understanding of the long term dynamics of infrastructure change, rather than instrumental and specific policy recommendations. We also note that high level systemic frameworks such as this do not provide in-depth insights into the political negotiation of different policy priorities and trade-offs being made. In the final section we draw key conclusions.

2. The UK electricity sector – background and investment challenges

We begin in this section by briefly outlining key aspects of the policy background to electricity sector transformation and low carbon investment in the UK. The UK, like many other industrialised nations, is currently facing the prospect of radical decarbonisation of its energy supply systems. The 2008 Climate Change Act set a legally binding goal of reducing the UK's greenhouse gas emissions by 80% by 2050, from 1990 levels, with intermediate carbon budgets to be set towards this goal, based on recommendations of an independent Committee of Climate Change (CCC). In its Fourth Carbon Budget report, the Committee (CCC, 2010) recommended that the UK should aim for a reduction in the carbon intensity of electricity generation from its current level of approximately 500 gCO_2/kWh to around 50 gCO_2/kWh by 2030, as a key element of reducing the UK's carbon emissions to this time.[1] Particular emphasis has been placed on the electricity sector, because relative to other energy intensive areas of socio-economic activity, it is seen as likely to be cheaper and more feasible to decarbonise electricity supply first due to the availability of alternatives (i.e. a range of renewables and nuclear power). Electricity generated from low carbon sources could then increasingly be used to meet other energy service needs for heating and transport.[2]

Fig. 1 below provides some background by showing the large coal, nuclear, combined cycle gas turbine (CCGT) generation plants and wind farms currently operating in the UK and the year they came onto the system. As can be seen, the vast majority of operating coal plants were constructed in the late 1960s/early 1970s and most of the UK's existing nuclear investments took place during the 1970s and 80s when the system was operated by a state owned body, the Central Electricity Generating Board (CEGB).

Much of the investment made by private companies following privatisation and liberalisation reforms in the 1990s has been in lower capital cost and flexible CCGT (gas) plant. Despite the new

[1] In 2011, the UK Parliament accepted the Committee's recommendation for overall carbon emissions reductions for the period 2023–2027, but did not agree to set a specific reduction target for carbon intensity of electricity generation.

[2] It should be noted that this view of an 'all-electric future' is not universally accepted. Some argue that there is too much emphasis on electrification, at the expense of potentially more effective means of decarbonisation of the heat and transport. For heat see: (Speirs et al., 2010).

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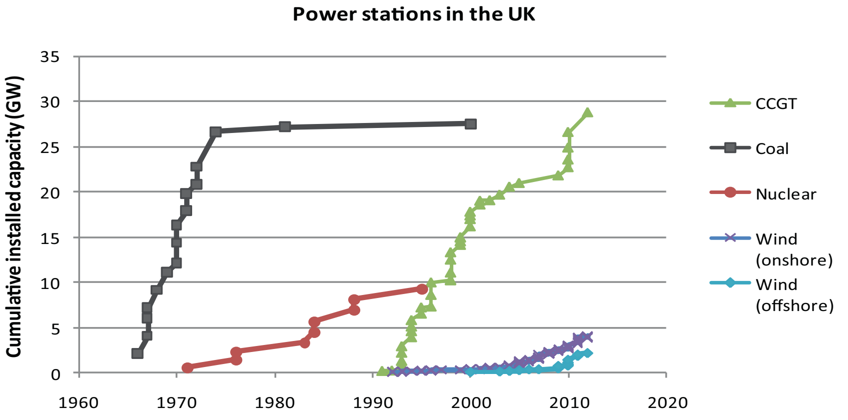

Fig. 1. Cumulative installed capacity (GW) of major power stations currently operating in the UK, with dates of installation (DECC, 2012a: data from Table 5.11). (In the interests of clarity this figure does not include non CCGT gas-fired generation, oil and diesel-fired generation, small scale solar and CHP, along with and other renewables such as hydro and biomass. Total generating capacity connected to the UK transmission network in 2012 was in the region of 90 GW.)

investments in CCGTs and wind farms which have taken place over the past number of decades, the UK faces a potential 'generation gap' as many of the existing coal and nuclear plant shown in the figure will come off the system over the coming decade due to ageing plant and a lack of compliance with environmental legislation (DECC, 2012b).[3] This has led to concerns over a short term threat to energy security due to a reduction in the level of spare capacity on the system – the capacity margin. The UK energy market regulator has recently estimated that the capacity margin could fall to about 4% by 2015, from current levels of 14% (OFGEM, 2012).

It is only since the introduction of a tradable obligation certificate programme, the Renewables Obligation (RO), in the early 2000s that significant levels of investment have taken place in renewable generation, primarily onshore wind farms. A notable feature of the UK approach has been the embedding of low carbon technology policy, such as the RO, in the day-to-day operation of energy markets. Broadly, this has meant that government is reluctant to interfere in the day-to-day operation of markets and influence the price levels for renewable output, rather it has set the quantity of low carbon generation (e.g. number of Renewable Obligation Certificates), and the price for this would be set by the market.

A key underpinning of the 'hands off' relationship which emerged since the 1980s between government and the industry has been basic assumptions of neo-classical economic theory (Mitchell, 2008) – that investment is most efficiently made by private actors on the basis of price signals mediated through the energy markets. The main aim of this approach has been to utilise market based incentives to improve the efficiency of the previously state owned energy industries, and the focus of policy has been on short rather than long term objectives – to reduce the day-to-day operational costs of generating and distributing energy to end users. On these terms the UK programme of privatisation and liberalisation can perhaps be regarded as a success (Pollitt, 2008), however, the UK is moving

[3] The Large Combustion Plant Directive requires large electricity generators to meet more stringent air quality standards as of January 2008. In many cases it will be too expensive for coal and oil plants to meet these standards and will therefore need to 'opt out' which means that they have to close by the end of 2015 or upon reaching 20,000 h of operation after 2008. DECC note that 'By the end of 2015. . .around 8 GW of coal-fired power generation capacity closes due to the Large Combustion Plant Directive'. In the medium/longer term there is uncertainty as to what effect the EU's Industrial Emissions Directive will have on coal plant closures. All but one of the UK's nuclear fleet is due to close by 2023, with Sizewell B expected to close in 2035. There is a great deal of uncertainty as to the exact timing of plant closures, in the case of Nuclear plant life extensions have been granted in the past, and in the case of coal plant market factors such as the carbon price and international coal prices influence plant economics and therefore their running hours.

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into a new phase of energy governance where new investment to meet long term climate policy and energy security objectives is the main priority.

A recently published UK Energy Research Centre working paper containing provisional results of a study on financing the low carbon transition has sought to account for the investment costs of replacing this capacity and meeting climate change targets in the UK context (Blyth et al., 2014). Following a review of previously published estimates Blyth et al. note that "Across all the scenarios assessed in this study, the average amount of new capacity needing to be added to the system was 3.4 GW each year up to 2020", and in terms of investment, "Estimates of the size of the investment challenge range from the often quoted DECC/OFGEM[4] figure of £110 bn by 2020 (including transmission and generation) to much higher figures ranging from £200 bn to over £300 bn by 2030 from organisations such as National Grid, the Committee on Climate Change and London School of Economics" (p. iii). They highlight that "These figures are considerably higher than the build rate during the 2000s which averaged 1.2 GW capacity added per year, with CAPEX of £1.1 bn per year" (p.iii).

Before its end of term in 2010 the then Labour government came to the conclusion that the current electricity market framework and associated support mechanisms, including the RO, did not provide sufficient incentive for private energy companies to invest in the levels of low carbon power generation needed to meet UK and EU renewable energy and carbon reduction targets. The deficiencies of the current market arrangement in relation to new low carbon investment was central to it setting in train an Electricity Market Reform (EMR) process, which was taken up by the new coalition government and is embodied in measures in the 2012 Finance Act (rising carbon floor price for power generation) and the 2013 Energy Act (contract for difference feed-in tariffs (CfD FITs), capacity mechanism and emissions performance standard). The likely success of these measures in stimulating high levels of investment in low carbon generation has been the subject of much debate, with some observers arguing that the EMR process was largely driven by the need to provide an incentive framework to support the building of new nuclear power stations[5] (Toke, 2011; Mitchell et al., 2011).

The proposed CfD FIT model introduces long term contracts for low carbon generation (renewables, nuclear and CCS) whereby a 'strike price' will be predetermined for each of the qualifying technologies, and generators will be remunerated if the market price is below this level. A key difference with the previous approach is that price will not be solely an outcome of market operation, but to a large extent determined by government decision. This is clearly a deviation from neo-classical economic principles which is characterised by increasing government intervention in the energy market. It now seems that the UK government is reluctant to let prices rise to a level required for new low carbon investment because of concerns over the impact on the affordability of energy to consumers. Instead, it is seeking to intervene in the market to spread out the costs of investment over a longer timescale and to socialise elements of investment risk, which it is hoped will reduce the cost of borrowing for private investors. A key argument of this paper is that government needs to do more than help private investors realise a return on large scale low carbon investments by socialising risk, if it is to achieve its carbon reduction targets. There may be potential to utilise this window of opportunity to rethink the basis on which energy policy is made and implement a more long term orientated approach which is based on an assessment of options and innovation outcomes, rather than like-for-like replacement of the current system.

3. Specific insights from socio-technical studies on low carbon investment in the UK power sector

The purpose of this main body of the paper is to discuss ways in which insights from socio-technical studies can be deployed with a view towards contributing to a new energy policy framework which is better equipped to address the challenges of low carbon investment and long term transformation.

[4] Department of Energy and Climate Change (DECC), Office of Gas and Electricity Markets (OFGEM).

[5] On 21 October 2013, the UK Government announced an agreement with French energy company EDF and its Chinese energy company partners to provide support for the building of a new 2 reactor 3.2 GW nuclear power station at Hinkley Point in South-West England, guaranteeing an index-linked price of at least £89.50 for each MWh generated for 35 years, https://www.gov.uk/government/news/hinkley-point-c.

The analysis is informed by two sources: the main source is work conducted as part of the 'Transition Pathways to a Low Carbon Economy' research consortium which both authors have been involved with (Foxon, 2013; Foxon et al., 2010). The interdisciplinary consortium, comprising engineers, economists and social scientists, has been developing and analysing alternative socio-technical scenarios, or pathways, for the UK to achieve its 2050 climate targets. In constructing these alternative futures, the consortium has drawn upon socio-technical insights to develop more robust methodologies for the analysis of the long term scenarios in energy systems. In Section 3.1 below, we argue that this approach can help to better frame uncertainty in energy transitions and to characterise associated investment risks.

Our second source is a qualitative analysis of key policy documents relating to UK government's approach to addressing the issue of power sector investment and a series of semi-structured interviews with actors in the energy/infrastructure investment chain; focusing on large institutional investors, investment managers, community scale investors, industry bodies and NGOs. To date 15 interviews have been conducted as part of a scoping study designed to develop a more in-depth understanding of the evolving relationship between energy policy and the investment community. A list of those interviewed is contained in an appendix at the end of this article. The interviews mostly provided background information to inform the main arguments in this paper. Our discussion in Section 3.3 of alternative investment models draws primarily from our interviews with individuals who have knowledge of the institutional investment community (primarily interviews: 1, 5, 6, and 9), and three individuals who are involved in the financing of small scale renewables (interviews: 3, 7 and 10). Subsequent publications will draw more specifically on the insights from these interviews.

The sections below draw from an initial analysis of this material and the work of the Transition Pathways project where we identify a number of challenges to be confronted by policy makers in relation to low carbon investment, highlighting key contributions from socio-technical thinking.

3.1. *Exploring uncertainty through coevolutionary pathways*

As outlined in Section 2 there is a great degree of uncertainty and debate regarding the optimal technical configuration and investment cost of decarbonising the UK electricity grid, particularly in the medium and long term. A recently published report from the UK Energy Research Centre has begun to identify the range of political, economic and technological uncertainties which could slow down or potentially derail the UK's low carbon transition (Watson et al., 2014). Key uncertainties are technological (relating to technology costs and system integration of renewables), economic (financial issues discussed above), natural resource availability, and political (what choices are made and by whom, public attitudes to different technology options) in their character. An understanding of the nature and origins of such uncertainty is of course critical in the context of investment in capital intensive assets where returns over the long duration of the investment need to be protected against uncertainty.

In his history of '*Great Transformations*' throughout the twentieth century, Blyth (2002) argues that structural change and economic crises are characterised by periods of "Knightian" uncertainty i.e. 'situations in which agents cannot anticipate the outcome of a decision and cannot assign probabilities to the outcome' (Beckert, 1996). Under these circumstances conventional approaches to evaluating investment risk, for example based on financial appraisal methodologies which rely on an identification and measurement of risks, become problematic.

Structural uncertainties at a system level which are influenced by policy and regulatory regimes tend to be poorly understood, one of the implications being that wider social risks and distributional effects are often poorly accounted for. There is therefore a need to think about uncertainties in an integrated and systemic way. In the past, scenario planning has been relied upon to explore the range of uncertainties influencing energy systems, particularly in the wake of the 1970s oil crises. However a recent review of low carbon scenarios, which are often based on conventional scenario methodologies, conducted by Hughes and Strachan (2010), identified a number of shortcomings of such approaches; primarily an "over-reliance on constructs, notably exogenous emissions constraints and high level trends, which diminish the ability to understand how the various future scenarios could be brought about or avoided" (Hughes and Strachan (2010: p.6065). Geels diagnoses two failures of traditional scenario methodologies (Geels, 2002a):

1. 'an implicit linear model of technological development'
2. 'undue emphasis on macro-logic and neglect of meso-logic'

A number of recent contributions to socio-technical studies have begun to develop new methodologies for scenario construction which are grounded in an appreciation of the interconnectedness of the social and technical and how future pathways of change are shaped by their coevolution. The method of socio-technical scenarios developed in the field has been deployed to examine how social and technical factors coevolve to shape alternative pathways of long term system change (Hofman and Elzen, 2010; Hofman et al., 2004). Geels (2002a) argues that the method 'can be particularly useful in 'fluid' and 'hot' situations, i.e. when the dominance of existing technologies is challenged by newly emerging technologies' (p.361). He goes on to argue that there is a need to think about scenarios in a multi-level way, incorporating the macro trends with an understanding of meso, or industry level, processes and specific micro level actor dynamics.

This methodology has been deployed in a number of studies to develop insights for long term energy innovation policy (Verbong and Geels, 2008; Foxon, 2013; Shackley and Green, 2007). These studies argue that the approach can contribute to a more realistic account of how the energy system might change over time. Drawing from the wider socio-technical literature, these types of scenarios take into account a number of complex processes and mechanisms including:

- Co-evolutionary processes – new interactions of technologies, institutions, business strategies, ecosystems and end user practices (Foxon, 2011).
- Multi-level interactions – how spaces of socio-technical reproduction (regimes) and transformation (niches) coexist and interact within a system, and are influenced by a wider system context (landscape) (Geels and Schot, 2007).
- Actor dynamics – the role and relative influence of different market, government and civil society actors in shaping technical change (Foxon, 2013).

These types of pathways could be used to explore investment uncertainty in a more structured and coherent way and how low carbon technology options might be constrained or enabled by wider governance and systemic factors.

3.1.1. *Illustration of pathways from the Transition Pathways project*

Taking these multi-actor/multi-level socio-technical processes as a basis for constructing alternative low carbon energy scenarios has been a central aim of the Transition Pathways project. A recent contribution by one of the authors (Foxon, 2013) draws on this methodology to develop and analyse three 'transition pathways' for the UK electricity system out to 2050. The pathways were constructed through an iterative process, starting with a dialogue between the consortium members, incorporating insights from sociology, economics and engineering, and subsequently a number of stakeholder workshops were held in an effort to bring in expertise from industry actors and policy makers. The final stages of pathway construction involved an assessment of the technical feasibility of the scenarios (for a fuller technical assessment of the pathways see: Foxon, 2013, Barton et al., 2013).

The three pathways specific to the UK context which emerged are based on how different actor framings of a low carbon future, or governance 'logics', which represent alternative policy and regulatory contexts, might influence and shape key multi-level and co-evolutionary processes:

- A '*market rules*' pathway (Fig. 2a) where a liberalised market framework prevails in which large energy utilities are the dominant investors. The key policy mechanism is a carbon price and private actors make their investment decisions based on this constraint;
- A '*Central coordination*' pathway (Fig. 2b) where national government exerts a strong influence over the energy system in order to deal with the 'trilemma' of addressing energy security, rising costs

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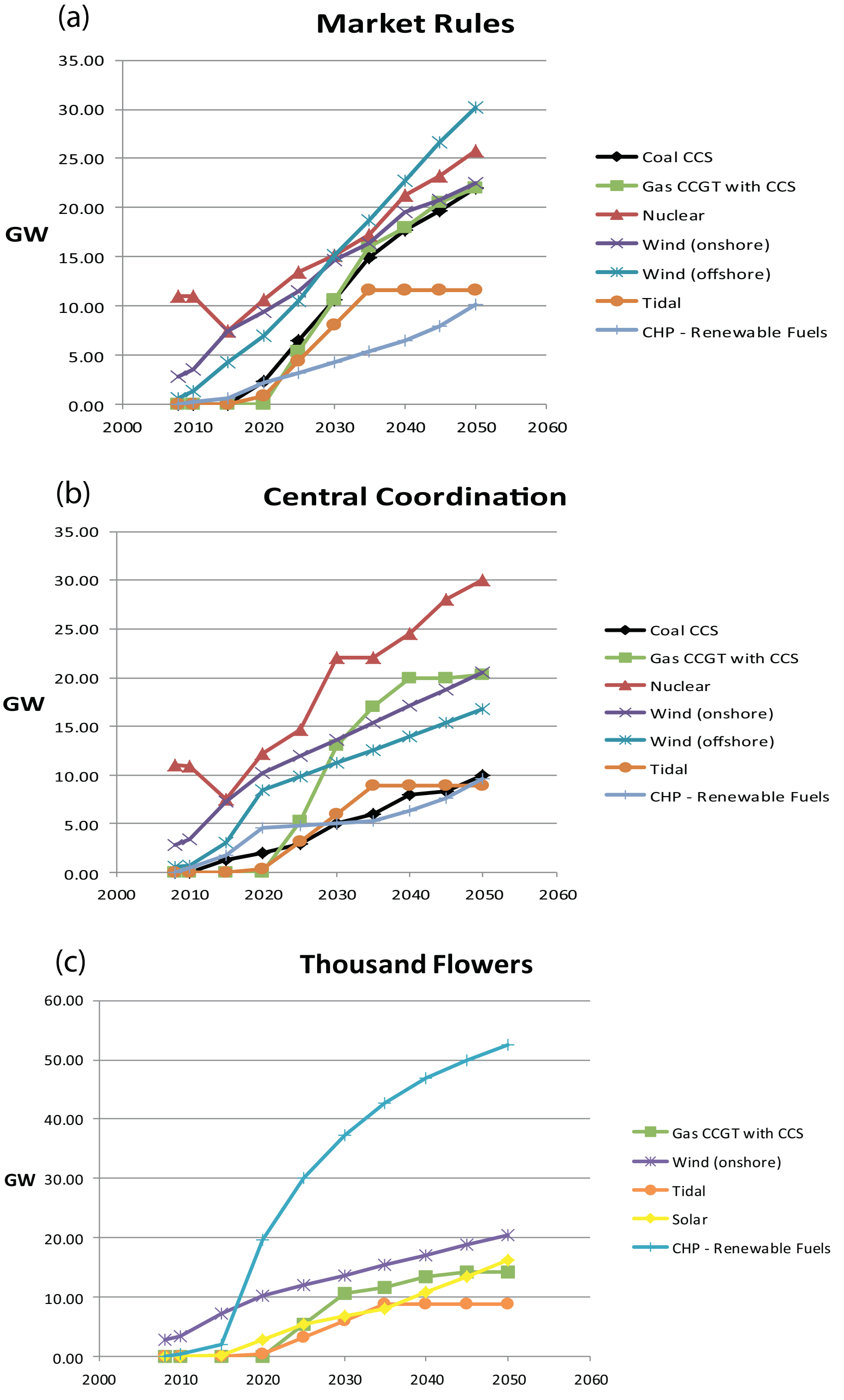

Fig. 2. (a)–(c) Investment pathways for the UK power sector. Data from the Transitions Pathways Project.

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and achieving emissions reduction targets. Government intervention is characterised by the setting up of a Strategic Energy Agency;
- A '*thousand flowers*' pathway (Fig. 2c) which sees a more decentralised future as non-traditional investors in the energy system, such as cooperatives and local authorities, play a leading role in investing in low carbon technologies and energy efficiency programmes.

Each of the pathways involve different mixes of low carbon generation (nuclear, carbon capture and storage and renewables) which diffuse as old coal and nuclear plants close (cf. Fig. 1) and CCGT is increasingly used as peaking plant rather than for base load. The graphs above, which are based on a quantitative assessment of the pathway narratives summarised previously, illustrate the diffusion of selected key low carbon technologies in each of the pathways.

In the *central coordination* pathway (Fig. 2a), a 'technology push' approach sees a focus on large scale centralised technologies such as nuclear, CCS and offshore wind. *Market rules* also sees a broadly centralised electricity system but with less reliance on nuclear power due to the lack of government backed long term contracts. *Thousand flowers* on the other hand sees a significant role for local and decentralised technologies such as CHP with district heating and small scale microgeneration technologies.

Largely due to the increasing electrification of heat and transport, meeting the 2050 decarbonisation target will necessitate a significant increase in installed capacity in 2050 (Central Coordination – 140.5 GW, Market Rules – 173.7 GW, Thousand Flowers – 148.5 GW, compared to the current UK generating capacity of 90 GW). This highlights the scale of the investment challenge to be faced in the coming decades in not only replacing existing fossil fuel capacity with low carbon technologies, but also in enabling the increasing electrification of heat and transport sectors.

3.1.2. Unpacking investment risk

This approach of exploring radically different socio-technical configurations could allow actors to think in a more systemic way about the relationship between risk and uncertainties associated with alternative governance processes and actor alignments. Thinking in terms of long term integrated pathways, where a portfolio of technologies, rather than single projects, can be considered at a system level could also be useful in formulating effective policy measures. Here an important question for policy makers will be to understand how their decisions regarding the design of regulatory frameworks for infrastructure investment can influence and potentially help to manage investment risk.

For large scale infrastructure systems, investment risk can be broken down into early stage financing and construction risks (e.g. planning delays, cost over runs, exchange rate fluctuations), technical/operational risks (e.g. risk of technical failure, higher than expected maintenance costs) and market risks (e.g. risk of lower than expected demand). Investors aim to quantify these risks in the light of future projections, but the risks are amplified by fundamental uncertainty over which, if any, low carbon pathway the county will follow. Investment risks therefore need to be understood in the context of these alternative socio-technical futures.

In the *central coordination* pathway there is a strong reliance on nuclear technology. Recent experience with new nuclear builds in Finland and France has highlighted the high risk of cost overruns, therefore raising the construction risk in this pathway. Similarly construction risk is a concern for investors in offshore wind farms (PWC, 2010), which is an important technology in the *central coordination* and *market rules* pathways. A question for government is therefore whether specific policies are required to mitigate this construction risk e.g. by creating a bridging mechanism which spreads risk between private investors and taxpayers/customers during the early project phase. This will have implications for the type of policies designed to attract finance, for example one of our interviewees noted that "some pension funds could be attracted to invest directly. . . [but] they would struggle with taking construction risk" (Interview 9).

This form of construction risk is perhaps less a feature of the more distributed *thousand flowers* pathway. However, market risk may become a more significant challenge in this pathway. This is because there is falling demand due to successful energy efficiency measures, many competing generators in the market, and a strong reliance on government subsidies in the form of feed-in tariffs. These market risks may lead to boom-bust investment cycles and create instability in the electricity sector. Mitigating this risk could necessitate a radically redesigned electricity market structure and a stronger political commitment to renewable support than has previously been displayed on the part of government.

3.2. *Understanding transition dynamics and the timing of investment decisions*

The discussion above highlights the implications of structural uncertainty in how low carbon transition pathways will evolve, in terms of new technologies, governance arrangements and actor roles. Operating in the midst of this uncertainty is of course an issue for government in setting long term regulatory frameworks, and private actors in making commercial investment decisions. This is difficult because infrastructure investments have long time horizons and in many cases investment decisions need to be made in the short term to meet immediate policy and economic goals, raising the risk of lock-in to potentially undesirable long term trajectories. The second area that socio-technical research can inform policy is how an understanding of path dependency and non-linearity in transition pathways can help to overcome this lock-in.

The wider technology studies literature on path dependency and lock-in (Arthur, 1989; David, 1985; Unruh, 2000) argues that technical change is not merely the product of an engineering or economic rationality, rather 'timing, strategy and historic circumstance, as much as optimality, determine the winner' (Unruh, 2000). Historical studies (David, 1985) and modelling exercises (Arthur, 1989, 1994) have highlighted how events and decisions made in the early stages of technological diffusion can be amplified and have enduring effects as 'winning' technologies, or dominant designs, benefit from positive feedbacks such as economies of scale, learning effects, adaptive expectations, and network effects as systems expand and become increasingly interconnected. These mechanisms can create a situation of lock-in, arising from the co-evolution of technologies with their wider institutional environment, which can in turn condition future decision making and constrain the scope for radical innovation (Unruh, 2000).

The transitions literature characterises this process of lock-in and path dependency in terms of socio-technical regimes (Geels, 2004) which are underpinned by strong inter-relationships between institutions, user practises, business strategies and infrastructures. Viewed through the lens of path dependency and lock-in, the evolution of regimes can be characterised by a number of distinct phases (Rotmans et al., 2001; Loorbach, 2007): a *predevelopment phase* characterised by gradual change and experimentation, with many competing technologies, a *take-off phase* with more evidence of structural changes where mechanisms of lock-in begin to take effect, an *acceleration phase* where dominant designs emerge and structural changes become more deeply embedded, and finally a *stabilization phase* where a new system state is reached and emphasis is on optimising the existing regime through incremental innovations. Of course this framework simplifies a more complex and messy reality where different phases of transition are not neatly defined and sequential, and the borders between one phase and the next are impossible to delineate. However, as a theoretical construct, it may provide a structured way of thinking through the policy and investment challenge of having to make near term investment decisions in the midst of uncertainty and which will have long term implications.

The energy transition in the UK is likely in the *predevelopment phase* or the early stages of the *take-off* phase as ambitious decarbonisation and renewable deployment targets have been put in place and structural changes to the electricity sector are beginning to be implemented. Winskel and Radcliffe (2014) have characterised the emergence of an 'accelerated innovation' imperative in the UK where the priorities of the energy innovation system is shifting away from diversity and the development of niche technologies, to achieving cost reductions in large scale technology programmes such as CCS and offshore wind, in order to achieve climate change targets. During this period the main priority is on the decarbonisation of the electricity grid, which according to the Committee on Climate Change will need to occur relatively rapidly by 2030, and following this a decarbonisation of the entire energy system will need to take place, incorporating the heat and transport sectors. As was outlined in Section 2, rapid power grid decarbonisation is seen as a first step primarily because there are a number of relatively mature low carbon options available (wind and nuclear), and in any case the UK will need to replace a number of its ageing coal, nuclear and gas plants over the coming decade. The technology options for decarbonising heat and transport are not so apparent and as a result there is much less certainty as to how the post-2030 *acceleration phase* will proceed. Creating a smooth transition from the *pre-development* and *take-off phase* of power sector decarbonisation to the subsequent *acceleration phase* where the entire energy system becomes low carbon is therefore key. The priority in the *take-off phase* is to develop investment strategies which help to 'future proof' the energy system by keeping options open as much as possible i.e. that do not close down the opportunities for niche innovations to become more widely diffused in the future. Also, in this phase the new skills, expertise, industrial capacity and supply chains which will also be required in the *acceleration phase*, will need to be developed.

Transition studies points to the danger of lock-in to sub-optimal long term pathways if decisions are made solely based on narrow short term criteria, e.g. the need to plug a gap in electricity generation capacity or to meet renewable energy targets for 2020, without building the necessary foundations required for a more fundamental transformation in the medium and long term. For example, a key argument for a 2030 electricity decarbonisation target is that this would help to stimulate the development of a renewables supply chain in the UK (Parr, 2013). A number of our interviewees identified the need to develop a UK manufacturing base in renewable technologies, with one interviewee from a large energy supplier noting that this is an immediate issue in particular for offshore wind: "demand for offshore wind is so strong that the capability of suppliers to meet that demand are being stretched to the limit, in some cases beyond the limit. So sometimes the capabilities in the supply chain are dictating the pace of the development, rather than demand" (Interview 2).

This suggests the need to develop alternative criteria which can help to evaluate investments aside from narrow short term economic ones. For example there may be certain strategic investments which help future proof the system for the post 2030 phase and create synergies across the transport, heat and electricity sectors. Taylor et al. (2013) argue that energy storage technologies fit into this category as they can help to manage a highly distributed and intermittent low carbon energy system, while Hawkey et al. (2013) argue for more emphasis on local scale infrastructure investments centred on the efficient provision of low carbon heat. However under current market structures the revenue streams to investors in these technologies which promote flexibility and efficiency are highly uncertain as their benefits are not specific to one particular segment of the market but diffused across the entire system, and are therefore more difficult to account for under current market arrangements (Bolton and Foxon, 2011, 2013b, 2014; Taylor et al., 2013). Addressing these deficiencies of energy markets and overcoming barriers to the diffusion of long term strategic investments will likely be key to moving into the *acceleration phase*.

3.3. Opening up the investment actor space: thinking beyond incumbents and creating diversity in low carbon finance

To date most of the low carbon investment in the electricity sector has been financed off the corporate balance sheets of the major utilities – in the UK the 'big six' energy utilities dominate the market. However, some influential actors within the business and investment community claim that this incumbent investment model may be inadequate to deliver the levels of low carbon investment required (CBI, 2011; PWC, 2010). There are two reasons for this: the first is that there is simply not sufficient financial capacity amongst the large utility companies in the UK (and most probably across Europe) who dominate the energy market to deliver the scale of the investment required under the timescales imposed by decarbonisation targets through traditional financing mechanisms. The second is the increasingly challenging business environment that large European utility companies now operate in where demand growth has stalled due to the economic slowdown. Also, unexpected energy policy developments have created uncertainty in the wider European energy market and in some cases has damaged incumbent utility balance sheets, most notably the German policy of accelerated nuclear shutdown and Spain's decision to retroactively reduce renewable electricity subsidies. In their 2011 National Infrastructure Plan (HM Treasury, 2011) the UK Treasury noted that "the principle sources of private finance for the UK's existing infrastructure pipeline – the balance sheets of utility companies and commercial banks – may face growing pressure in the medium and long term" (p.97).

In a recently published report investigating the issue from a UK perspective by Blyth et al. (2014) it was noted that: "Traditional utility companies have recently faced difficult market conditions, with significant demand destruction across Europe as a result of the recession, leading to excess capacity and

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low margins. In the 2000s, utilities took on much higher debt levels to fund mergers and acquisitions across Europe. Energy companies are now attempting to de-leverage their balance sheets in order to maintain reasonable credit ratings and access to the low-cost bonds and shares on which their business model depends. This constrains their ability to raise debt to cover increased investment" (p.iv).

Emphasising this dilemma, an interviewee from one of the large UK utilities stated that "we've all suffered with the last few years, everyone's balance sheets have suffered and nobody. . .is in a position to massively finance new programmes. . .This is a massive unparalleled level of investment. I think that that is a very very tricky situation to work though" (Interview 13). Blyth et al. (2014) highlight that the real challenge may come in the UK in the post-2020 period where, in order to meet ambitious decarbonisation goals under the fourth and subsequent carbon budgets, a rapid scale up of low carbon finance will be required and there may be a need to diversify the sources of low carbon finance.

3.3.1. Can government foster low carbon finance 'niches'?

Historical studies of previous phases of structural change have highlighted the role of government in aligning capital flows with long term innovation processes. The work of Carlota Perez for example has emphasised that the issue of redirecting financial capital to more productive ends has been a recurrent feature of the capitalist system following financial and economic crises. Once realignment between technology and finance is achieved, Perez argues, there is potential for a 'golden age' where financial capital supports the development of productive technological systems, enabling in the past significant investment programmes in infrastructures such as canals, railways, and telecommunications (Perez, 2002, 2013). However, because low carbon investment will need to be policy driven rather than by benefits to private investors, as has historically been the case (Pearson and Foxon, 2012; Perez, 2013), significant uncertainties remain as to how large scale investment which contributes to the societal goal of reducing carbon emissions can be brought about. In line with socio-technical studies, there may be a role for government intervention to facilitate and grow new and innovative forms of finance. The transitions approach emphasises the need to develop and foster 'niche' spaces or incubation rooms for radical innovation which, although may be underdeveloped and uncompetitive against incumbent technologies, have the potential to diffuse and alter mainstream regimes further down the line (Raven, 2005; Coenen et al., 2010). These arguments may be equally as applicable to the ways in which low carbon infrastructure is financed, as to the technological innovations themselves.

Of course, large energy companies will continue to play an important role, particularly in delivering large renewables, CCS and nuclear as they have significant knowledge and expertise in developing large and complex infrastructure projects. However, increasingly attention is being drawn towards alternative sources of finance. Below we outline four potential low carbon finance 'niches' which have been identified through our discussions with interviewees:

- *Energy cooperatives* are perhaps the most established form of alternative energy financing, dating back to the early development of wind energy in Denmark. This is primarily an equity based approach where ownership is confined to members who hold shares in the cooperative, the principle being that those who benefit from the cooperative control it. In the UK, cooperatives have tended to be community based investment in small scale wind farms, and in recent years, following the introduction of dedicated feed-in tariffs for microgeneration, they have supported the building of small and medium scale solar installations.
- *Energy service companies (ESCos)*, unlike incumbent utilities base their business model on the provision of energy services in the most efficient way possible, and in some cases use the projected returns from efficiency savings to finance new investments. A UK based ESCo, Thamesway Energy, which is wholly owned by Woking borough council, partly financed investments in CHP plants and district heating infrastructure by savings from energy efficiency measures. Private companies also operate in this space by providing energy performance contracting to customers, meaning that customers can install technologies such as domestic microgeneration at little or no upfront capital cost (Hannon et al., 2013).
- Forms of *investment disintermediation* where financial intermediaries such as banks and investment funds are bypassed in the investment process have gained increasing attention following the financial crisis. There is one example in the UK of such activity in the renewable energy sector; Abundance

Generation,[6] who are attempting to directly link individual retail investors with project developers. In this case the developer retains ownership of the scheme but issues debt debentures to raise finance, which are not listed on a stock exchange but sold to individuals who can subsequently sell them on.

- The final financing niche we point to are new ways of *engaging institutional investors*. The question of how to engage with and attract institutional investors, primarily pension and insurance funds, into the low carbon sector has become an increasingly central part of mainstream energy policy debates in the UK, and there has been much discussion surrounding the potential role that innovative financing mechanisms such as green infrastructure bonds could play in this. These types of investor who hold large pools of capital would not traditionally have invested in the electricity generation sector. However, the long term nature and potential for predictable returns which are protected against inflation are attractive for these investors, particularly for maturing pension funds. As discussed previously, it will be critical to allocate investment risk between private investors, customers and taxpayers in an equitable manner and to engender greater confidence in the long term prospects for low carbon investments. Blyth et al. (2014) note: "there does seem to be a growing appetite amongst institutional investors to put more money into infrastructure funds, and some estimates suggest that the amount of money available could increase by a factor of 2 or 3 (up to $6.5 tn)" (p.vii).

The literature on niches for sustainable innovation highlights three key areas of niche governance that require attention (Smith et al., 2014; Smith and Raven, 2012): the first is niche *shielding* where radical innovations are protected from the prevailing market or 'selection environment', e.g. through subsidies, the second is *nurturing* where the development and growth of innovations is enabled, and the third is *empowering* where niches begin to interact with and influence the incumbent regime. These aspects of governing niche innovation will have different implications for the examples outlined above. For example, energy cooperatives where shareholders retain direct control are likely to be limited in the size of projects they can develop and will rely strongly on forms of government subsidy for small scale decentralised technologies such as feed-in tariffs for their long term survival. On the other hand, approaches which engage with institutional investors and the wider capital markets are potentially more scalable and closely aligned with the incumbent regime rules and technologies. In this case, the focus of policy should be on short term intervention, playing a catalytic role and increasing investor confidence, with the expectation that the niche will rapidly become self-sustaining.

In 2012 the UK Government initiated a Green Investment Bank, a public organisation to stimulate investment in the low carbon sector. A more in-depth review is required to explore the extent to which such public lending institutions can accelerate the scaling up and diffusion of different forms of non-traditional ownership and financing, and the ways in which policy can protect and nurture these niches in appropriate ways, encouraging new forms of learning in this area.

4. Discussion and reflection on policy contributions

In this section we reflect on the nature of the contribution that socio-technical systems analysis can make it in providing an overarching framework for the development of energy policy in relation to low carbon investment.

Recent analyses of energy policy and politics in the UK have suggested that economic theories and methods have been extremely influential in formulating and structuring the market based paradigm of energy governance in the UK since the 1980s (Kern et al., 2013). In this sense economic theory has played a performative role (Mackenzie et al., 2007; Callon, 1998), not only has it sought to understand the structure and functioning of energy markets, it has played an important role in initially designing them and bringing them into being. It seems increasingly clear however that this economics based model is incapable of delivering the type of low carbon investment required over the necessary timescales, and that government needs to step in to redirect and channel finance into the sector. Considering the influential role that neo-classical economics played in bringing into being the

[6] https://www.abundancegeneration.com/about/.

last radical socio-technical shift in UK energy – privatisation and liberalisation – it may be the case that there is scope for a new and renewed dialogue between academic discourse and policy.

In reflecting on the contributions from socio-technical systems studies outlined, the strength of the approach may be in providing overarching frameworks based on a systems understanding, rather than guidelines on specific short interventions. The nature of this type of relationship between technology studies and policy has been outlined by Russell and Williams (2002) who argue that the field 'can make a significant contribution to the current rethinking of approaches to technology policy: in general through a reconceptualising of its key problems and concerns, and specifically formulating or improving particular forms of policy analysis and practice' (p.146). Russell and Williams argue that this new form of policy informed by technology studies will be different in that it 'does not feed into policy-making in a single and simple way. . .It is highly unlikely that its use will be direct and instrumental in the manner depicted by technocratic policy models' (Russell and Williams, 2002: p.146). A more nuanced understanding of the social character of technical change and the non-linear and complex dynamics of innovation processes can help policy makers 'to identify possible points of intervention' and assess the 'the dynamics of policy intervention' e.g. in relation to innovation outcomes (Russell and Williams, 2002: p.146).

A danger of course of focusing on long term socio-technical processes and speaking in terms of system level frameworks is that the real world, day-to-day messiness of socio-technical change is glossed over. For example the ideal type governance logics discussed in Section 3.1 – government, market and civil society – do not exist in isolation, rather socio-technical change will be politically negotiated, the transition pathway taken will be shaped by conflict and forms of alignment between these worldviews.

Insights can be drawn here from recent contributions to the political economy of energy systems and structural change (Kuzemko and Bradshaw, 2013; Newell and Mulvaney, 2013; Bradshaw, 2010). Areas of increasing politicisation in the UK in relation to energy investment, such as rising energy bills and contestation surrounding different technology options e.g. shale gas, nuclear power etc., are shaped by trade-offs between long term decarbonisation goals and shorter-term objectives relating to security of supply and affordability of energy services, which may be perceived as more pressing by policy makers. Elsewhere (Foxon, 2013) one of the authors has characterised this arena of conflict and negotiation in terms of an 'action space' between government, civil society and market governance logics. Powerful actors enrol others into their worldview, alliances are formed leading to the dominance of one logic, or the formation of hybrid pathways (Bolton and Foxon, 2013a).

More empirically grounded research could explore in more depth how ongoing actor dynamics and political processes might influence investment decisions and the implications for long term trajectories of socio-technical change.

5. Conclusions

In this paper we highlighted how the extant literature on socio-technical systems can be operationalised to address important questions on the role of policy in effectively mobilising finance to achieve low carbon objectives in the UK electricity sector. In the sections above we have illustrated a number of ways in which the basis for policy making in this area could be enhanced: firstly, by developing long term energy scenarios for the analysis of investment risk and uncertainty which are sensitive to actor dynamics and structural changes in the system of governance; secondly, by sensitising policy interventions to the dynamics of long term transition processes in an effort to explore options and improve the potential for innovative solutions; and, thirdly, by emphasising the need to foster diversity and learning processes in the area of financial innovation.

In the UK, as in other countries, new policy frameworks are required to guide the transition from an energy governance model centred on achieving short term efficiencies through market operation, to a long term approach which is resilient and adaptive in the face of new uncertainties. We have argued that socio-technical systems frameworks, combined with empirical analysis, can provide useful frameworks to address these types of questions and inform wider societal debates on low carbon investment options.

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Appendix. List of interviewees and dates

1. Head of Sustainability at a large investment fund. 14-1-2013
2. Head of renewables policy at a major UK energy utility. 15-1-2013
3. Company secretary of an energy cooperative. 25-1-2013
4. Managing Director of energy innovation at a major UK energy utility. 24-1-2013
5. Head of Advisory at a specialist environmental investment group. 11-2-2013
6. Partner at an advisory firm specialising in private equity and infrastructure investments. 4-2-2013
7. Co-founder and director of an investment company specialising in small scale renewables. 5-2-2013
8. Partner and Head of Sustainability Research at an investment group specialising in sustainability. 6-2-2013
9. Investment Director at a European investment Fund specialising in energy, climate change and infrastructure. 25-2-2013
10. Individual renewable energy project developer. 28-2-2013
11. CEO of a NGO which campaigns for sustainable investment practices in the pensions sector. 6-2-2013
12. CEO of an investment industry professional body promoting sustainable investment practices. 4-4-2013
13. Senior member of the commercial department of a major UK energy utility. 5-4-2013
14. Employee in the Investor Relations team of an energy related government agency. 14-6-2013
15. Senior civil servant working on renewable deployment. 9-8-2013

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